Space Technology Research Grants

A Numerical Method to Generate Reference Trajectories for Optimization Methods to Support Low-Thrust Mission Design

Completed Technology Project (2016 - 2020)

Project Introduction

The recent success of missions employing low thrust propulsion systems has demonstrated the promise this technology holds for a wide array of future applications, from asteroid tours, to missions to Mars. Low-thrust spacecraft motion is governed by a sensitive system of nonlinear differential equations, and this makes finding desirable trajectories challenging. Current low-thrust trajectory design methods rely heavily on optimization techniques to obtain feasible trajectories. These techniques require an initial guess for the spacecraft trajectory and this guess heavily impacts the final optimized trajectory. Many locally optimal trajectories are available and a precise initial guess can lead to the most desirable locally, or even globally, optimal trajectory. Despite the importance of a good initial guess in low-thrust trajectory design, relatively few comprehensive methods exist for creating these guesses. A method for generating a wide array of initial guesses and selecting one that best fits a set of preferred criteria is desirable because it would expand the range of possible low-thrust trajectories. One tool that shows promise for developing initial guesses for low-thrust trajectories is the theory of invariant manifolds. In astrodynamics, invariant manifolds can be thought of as structures that show the natural flow of gravitational forces about a periodic orbit. The manifolds of low-thrust periodic orbits are likely helpful for producing a range of detailed initial guesses for low-thrust trajectories. The proposed investigation will study how the manifolds of low-thrust periodic orbits can be used to produce improved initial guesses for low-thrust spacecraft trajectories. The study will begin by computing low-thrust periodic orbits and obtaining the manifolds of these orbits. Following this, a variety of visualization methods will be employed to understand manifold behavior, these include Poincare maps and three-dimensional plots. The intuition gained from these visualizations will be used to develop a scheme for categorizing manifold behavior. Understanding gained from visualization and categorization will be applied to low-thrust mission design. A number of realistic mission scenarios will be tested, including polesitting orbits and transfers from the Earth-Moon system to other bodies. It is important to note that a spacecraft can leverage the manifolds of a low-thrust periodic orbit without entering the orbit. Therefore, a low-thrust periodic orbit does not need to be the final destination of a spacecraft in order for this mission design method to be of use. The proposed mission design method will first identify low-thrust periodic orbits whose manifolds provide access to the desired regions of space. Next, the method will calculate the manifolds which provide the preferred trajectory characteristics at the lowest cost. The result of this determination will be used as an initial guess in an optimization technique. Finally, the resulting solution will be tested in a higher fidelity model. This entire process will be made as autonomous as possible to allow for ease of use by mission designers. The improved initial guesses generated by this method will produce superior locally optimal trajectories, which could entail fuel or time savings for spacecraft. Therefore, mission design strategies produced by this study could yield innovative trajectories that would reduce mission cost

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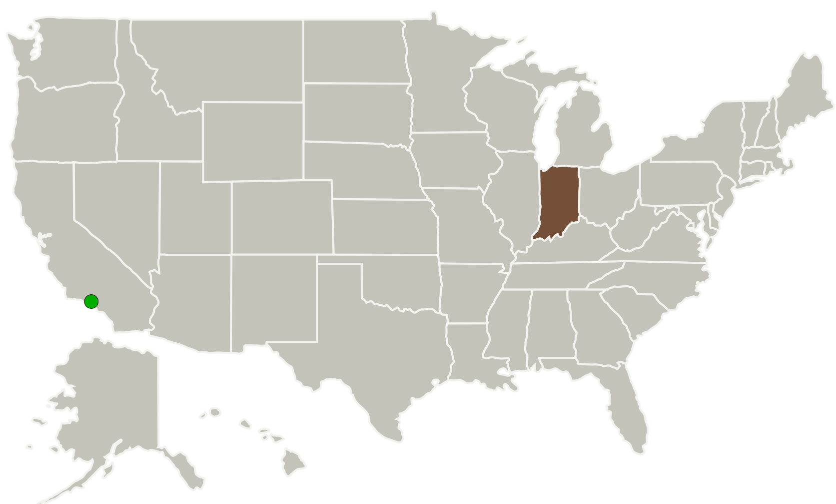
and increase scientific return. Furthermore, this research will yield methods for understanding the stability of low-thrust enabled periodic orbits. The potential of low-thrust spacecraft has only begun to be realized. Investment in astrodynamics research will expand the space attainable by these spacecraft, opening up new regions of space for science and exploration by NASA and its partners.

Anticipated Benefits

The improved initial guesses generated by this method will produce superior locally optimal trajectories, which could entail fuel or time savings for spacecraft. Therefore, mission design strategies produced by this study could yield innovative trajectories that would reduce mission cost and increase scientific return. Furthermore, this research will yield methods for understanding the stability of low-thrust enabled periodic orbits. The potential of low-thrust spacecraft has only begun to be realized. Investment in astrodynamics research will expand the space attainable by these spacecraft, opening up new regions of space for science and exploration by NASA and its partners.

Primary U.S. Work Locations and Key Partners



Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Purdue University-Main Campus

Responsible Program:

Space Technology Research Grants

Project Management

Program Director:

Claudia M Meyer

Program Manager:

Hung D Nguyen

Principal Investigator:

Kathleen M Howell

Co-Investigator:

Robert E Pritchett

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Organizations Performing Work	Role	Type	Location
Purdue University-Main Campus	Lead Organization	Academia	West Lafayette, Indiana
Jet Propulsion Laboratory(JPL)	Supporting Organization	NASA Center	Pasadena, California

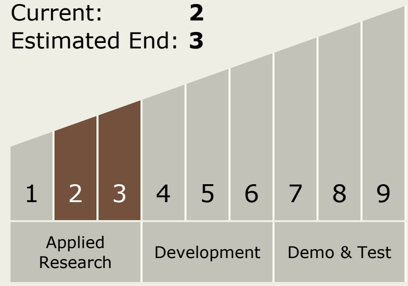
Primary U.S. Work Locations
Indiana

Project Website:

https://www.nasa.gov/strg#.VQb6T0jJzyE

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **3**



Technology Areas

Primary:

- TX17 Guidance, Navigation, and Control (GN&C)
  └ TX17.2 Navigation Technologies
    └ TX17.2.6 Rendezvous, Proximity Operations, and Capture Trajectory Design and Orbit Determination

Target Destinations

Mars, Others Inside the Solar System